



# Venus Balloons For High Altitude

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# Introduction



- Any discussion of Venus balloons has to acknowledge the accomplishment of the Soviet VEGA mission that flew two balloons at Venus in 1985.
  - These are the only balloons to have ever flown at another planet
- Two identical copies flew for 2 days each, carried as secondary payloads on the VEGA 1 and VEGA 2 landers.
- Metrics:
  - Type: helium-filled spherical superpressure
  - 3.5 m diameter
  - Teflon-like coated fabric material
  - 7 kg payload
    - Temperature, pressure, illumination, aerosol and wind measurements
  - 53-55 km altitude (in the clouds)



VEGA prototype test

- Ambient temperature  $\sim 30^{\circ}\text{C}$
- Aerially deployed and inflated
- Battery-powered
  - Balloons still flying when batteries died



# Venus Ballooning at High Altitudes

- The challenge of ballooning at high altitude (60-75 km) at Venus is that the atmospheric density is low:

Altitude (km)	Density (kg/m <sup>3</sup> )
55	0.92
60	0.47
65	0.21
70	0.084
75	0.033

- Buoyancy scales with volume\*density
- $\rho (75 \text{ km}) / \rho (55 \text{ km}) = 0.036$ 
  - A factor of 28 less than the VEGA balloon altitude.
- Venus at 75 km has the same density as the Earth at 22 km (69,000 ft).

# Consequences of Low Atmospheric Density



- Since the buoyancy (floating mass) per unit volume is less, one must:
  - Have a smaller payload for the same size of balloon, or
  - Use a larger balloon
- A complicating factor with using a larger balloon is that the mass of the balloon itself also grows and takes away from payload mass.
  - $M_{\text{pay}} = V_{\text{bal}} * (\rho_{\text{atm}} - \rho_{\text{gas}}) - M_{\text{bal}}$
  - Use of lighter and/or stronger balloon materials can help.
    - The VEGA material was relatively heavy,  $\sim 300 \text{ g/m}^2$
- Earth balloons regularly fly at atmospheric densities of  $0.033 \text{ kg/m}^3$  and less.
  - But this is typically done with balloons constructed from very lightweight balloon materials, such as  $25 \text{ }\mu\text{m}$  (1 mil) thick polyethylene film with an areal density of  $\sim 25 \text{ g/m}^2$ .
- In principle, there's no reason why you can't fly a balloon at 75 km at Venus, but the design details will be dictated by the kind of mission you want to fly.

# Balloon Option #1: Polyethylene Zero Pressure



- The workhorse for high altitude scientific ballooning on Earth is a helium-filled, zero pressure balloon made from very lightweight polyethylene film.
  - It can be used at Venus because polyethylene is tolerant of sulfuric acid.
- Zero pressure means there is only a tiny bit of pressure difference across the envelope due to hydrostatic forces.
  - It is achieved by having an open vent to the atmosphere so that solar heating or atmospheric perturbations cannot pressurize the helium during flight.
- This kind of balloon is neutrally stable: altitude can only be maintained by a combination of helium gas venting and ballast drops.
  - Eventually you run out of these consumables, which ends the flight.
  - On Earth, it is difficult to last more than a couple of diurnal cycles.
- Conversely, this kind of balloon is well-suited to conducting altitude excursions, you just need a control system and enough ballast.

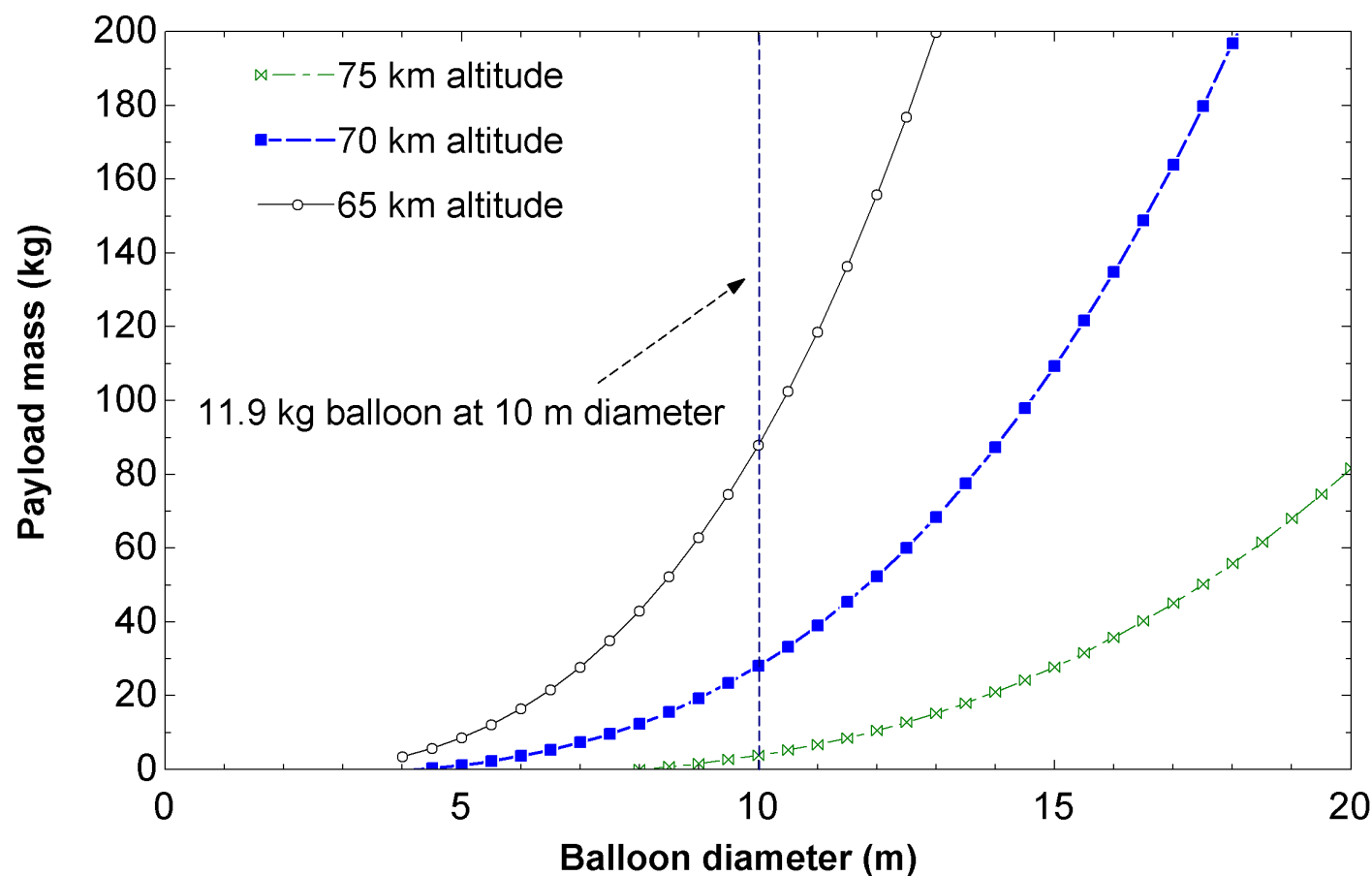


Very large polyethylene zero pressure balloon



# Balloon Option #1: Notional Designs

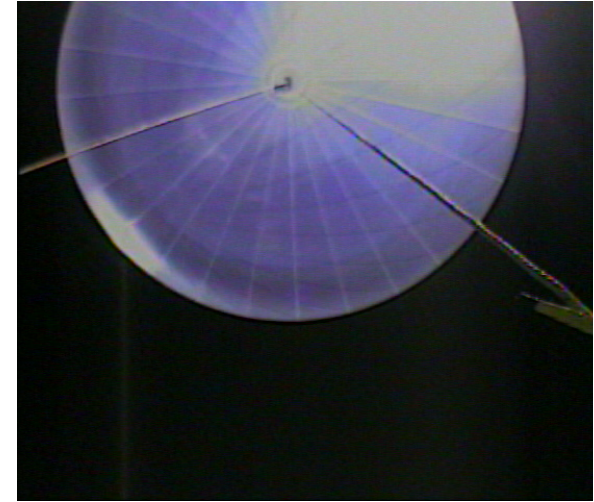
- Parametric curves generated below using 25 micron (1 mil) PE film.
  - Does not include ballast.
- 75 km altitude significantly more challenging than 65 km.



## Balloon Option #2: Spherical Superpressure



- The second option is a helium-filled, spherical superpressure balloon.
  - VEGA was this type of balloon.
- Superpressure means that it is a constant volume, closed balloon that changes pressure when heated or perturbed in altitude.
  - The pressurization can be substantial, requiring a strong balloon material.
- The VEGA material is too heavy and weak for high altitude flight.
  - Terrestrial versions typically have been made from polyester (Mylar) film, but this material does not tolerate the expected sulfuric acid concentration (>85%).
  - Therefore, some kind of Teflon coating would need to be added.
- A superpressure balloon is stable and will return to its equilibrium altitude if perturbed.
  - This is great for achieving long flight duration (no consumables). Terrestrial examples have achieved 2+ year flight durations.
  - But it is not good for conducting altitude excursions.

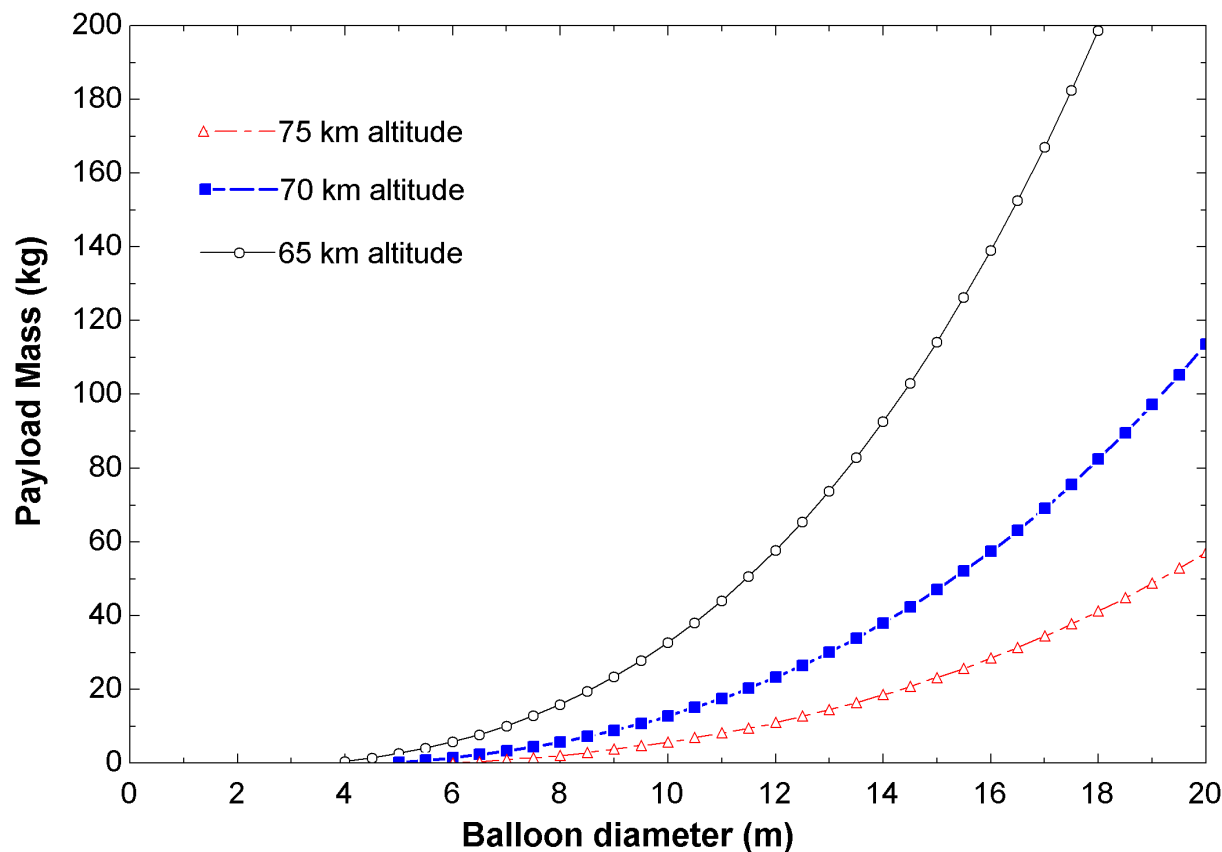


12 m Mylar spherical superpressure balloon flying at 30 km on Earth.



## Balloon Option #2: Notional Designs

- Parametric curves generated below using Teflon-coated Mylar film of variable thickness to contain the superpressure at altitude.
- 75 km altitude significantly more challenging than 65 km.
- Lower payloads at a given diameter than the zero pressure design.





# Balloon Option #3: Altitude Cycling Balloons



- There are two main altitude cycling concepts for balloons that do not have consumables:
- Solar-heated hot air (Montgolfiere) balloons.
  - Filled with atmospheric gas.
  - Buoyancy produced by solar heating during the day, and IR heating from the planet at night.
  - Could cycle indefinitely between 60 and 75 km.
  - CNES has flown this kind of balloon on Earth for decades.
- Phase change fluid balloons.
  - Filled with a fluid that is a gas at 60 km and a liquid at 75 km (phase change fluid).
    - Low temp at higher altitudes causes condensation.
  - Water was previously studied for the 40-60 km range, but no significant work done on higher altitudes.
  - In principle, can get more frequent altitude excursions than one per diurnal cycle hot air balloons.
  - Some limited terrestrial flight tests have been performed on this kind of balloon.



Solar Montgolfiere balloon (JPL Mars balloon flight test circa 1999)



Phase Change fluid balloon (JPL flight test circa 1996)

# Aerial Deployment and Inflation



- All Venus balloons require an aerial deployment and inflation sequence upon arrival at Venus to transition from a folded, stored state to a flight condition.
- For VEGA, this occurred over a few minute period during a parachute-assisted descent through the clouds.
- This process includes injection of the buoyancy fluid or heating of the ingested atmosphere depending on which kind of balloon you have.
- The VEGA success is a proof-of-concept that Venus balloon aerial deployment and inflation is feasible.
  - But any specific new design will require a verification and validation process to prove viability.
  - This is not likely to be a major risk item: the Venus atmosphere is very dense providing lots of time to deploy and inflate, and the Venus balloons themselves tend to be robust.
- A key design characteristic is that the balloon finishes inflation at an altitude below the equilibrium float altitude and rises to that point after inflation.
  - VEGA did this to avoid overpressurizing the envelope at excessively high altitudes.
  - It allows us to deploy at balloon at an “easy” 55 km and then ascend to 65-75 km.

# Discussion



- Balloon Options 1 and 2 are straightforward applications of established terrestrial balloon technology and can be considered at high maturity.
- The cycling balloon options (#3) are less mature.
  - Feasibility of the solar Montgolfiere balloon rests on accurate predictions of solar and IR fluxes (and other properties) in the Venus atmosphere. Much work remains to be done to quantify the performance envelope and assess risks.
  - Phase change fluid balloon designs have not been done in detail for the 60-75 km altitude regime. This concept is generally at a low maturity and requires substantial development for the heat exchanger components for the balloon and payload.
- Note that the phase change fluid balloon is perhaps uniquely able to provide long duration flight in the lower atmosphere of Venus ( $< 50$  km).
  - Cooling of the payload is a formidable challenge to long duration flight in the hot lower atmosphere of Venus.
  - Phase change fluid balloons can periodically ascend to the high, cold region of the atmosphere and cool off the payload, thereby enabling indefinite flight durations.
  - This thermal advantage is not needed for exploring the upper atmosphere, but there are clear synergies between the two altitude regimes for this type of balloon.



# Conclusions

- There are multiple concepts for using balloons to explore the upper atmosphere (60-75 km) of Venus.
- Zero pressure and superpressure designs are commonplace on Earth and would readily transfer to Venus.
  - Zero pressure balloons provide the ability to conduct altitude excursions at the cost of reduced mission durations (probably 1 or 2 diurnal cycles).
  - Superpressure balloons can fly for very long durations, but are fixed in altitude to something like  $\pm 1$  km.
- Montgolfiere and phase change fluid balloons offer the promise of both altitude excursions and long flight durations, but require technology development to verify feasibility and performance.
- The phase change fluid balloon is also applicable to long duration, low altitude exploration as a result of its ability to keep the payload cool by rejecting heat to the environment during the periodic excursions to the cold upper atmosphere.